NASA Space Technology

Presented at the IPPW Short Course

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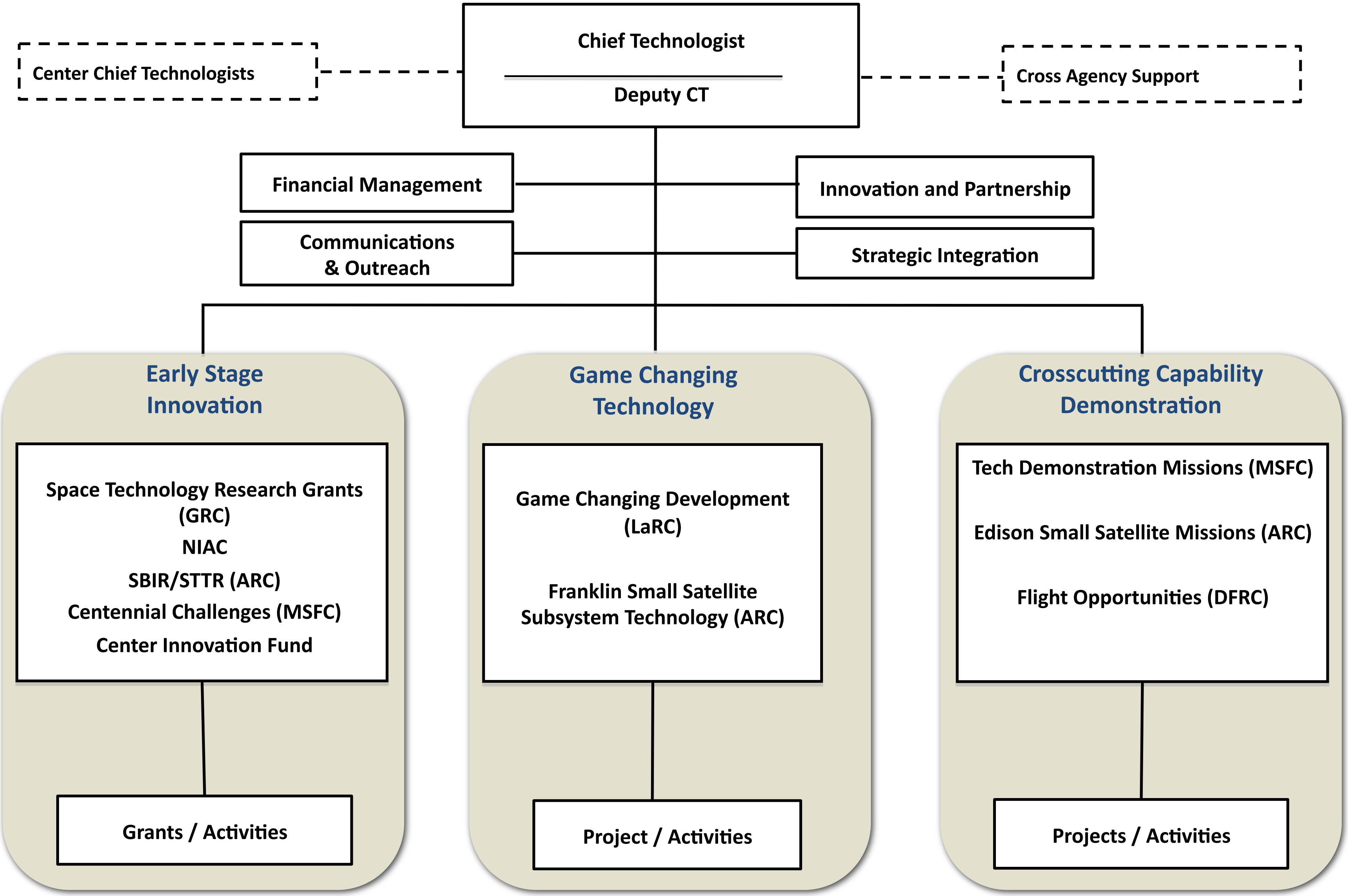
Space Technology

- **Space Technology is a budget line in the FY11 and FY12 President's request for NASA**
  - Consists of **10 technology development and innovation programs** that are broadly applicable to the Agency's aeronautics, science and exploration enterprises
  - Managed by Office of the Chief Technologist (**OCT**)
- **OCT has chosen to manage these 10 programs through the formation of 3 Divisions**
  - Early Stage Innovation
  - Game Changing Technology
  - Crosscutting Capability Demonstrations
- **Space Technology builds on the success of NASA's Innovative Partnerships Program (IPP)**
  - In FY11, IPP is integrated into Office of the Chief Technologist and the IPP budget is integrated into the Space Technology Program
- **Formulation of the Space Technology program is complete**
  - Formally approved by the NASA Administrator at July 29, 2010 Acquisition Strategy Planning meeting

Office of the Chief Technologist Organization

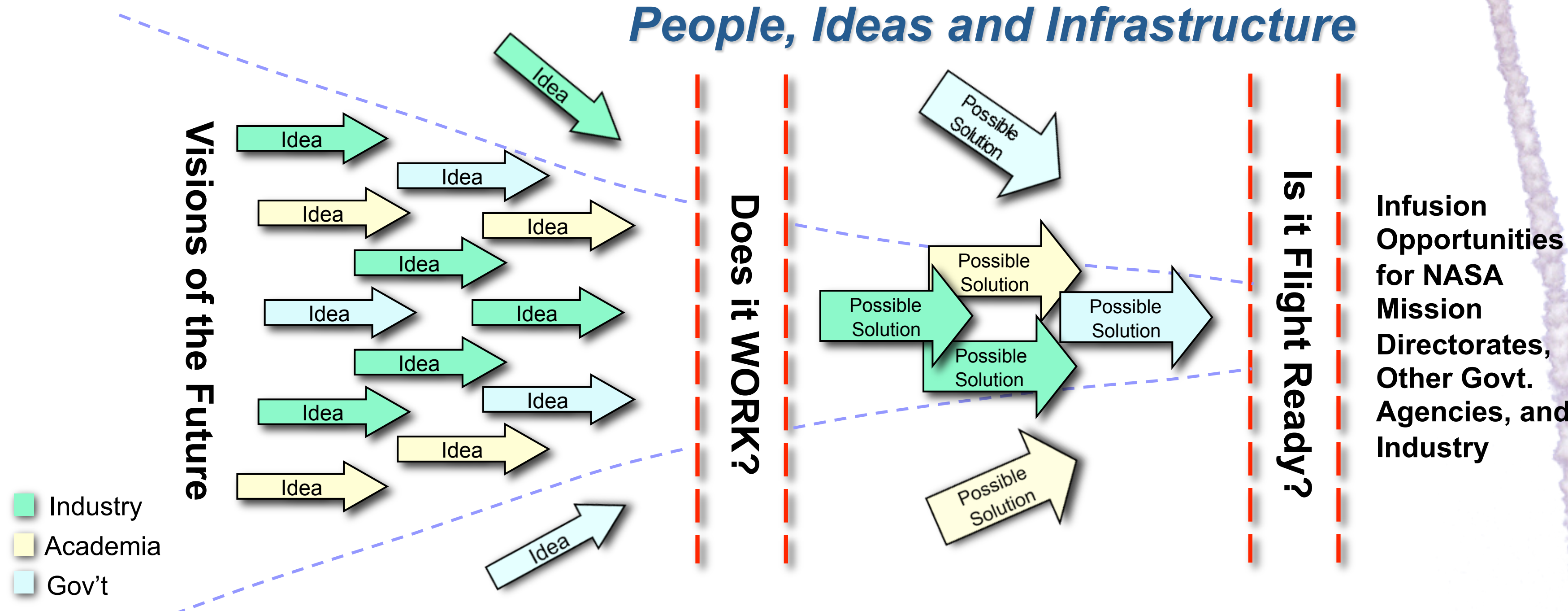


Space Technology: A Different Approach

- **Strategic Guidance**
  - **Agency Strategic Plan**
  - **Grand challenges**
  - **Technology roadmaps**
- **Full spectrum of technology programs that provide an infusion path to advance innovative ideas from concept to flight**
- **Competitive peer-review and selection**
  - Competition of ideas building an open community of innovators for the Nation
- **Projectized approach to technology development**
  - **Defined** start and end dates
  - Project Managers with **full authority and responsibility**
  - Project focus in selected set of **strategically defined capability** areas
- **Overarching goal is to re-position NASA on the cutting-edge**
  - **Technical rigor**
  - **Pushing** the **boundaries**
  - **Take informed risk**; when we fail, fail fast and learn in the process
  - Seek **disruptive** innovation
  - Foster an **emerging commercial space** industry

Space Technology: A Different Approach

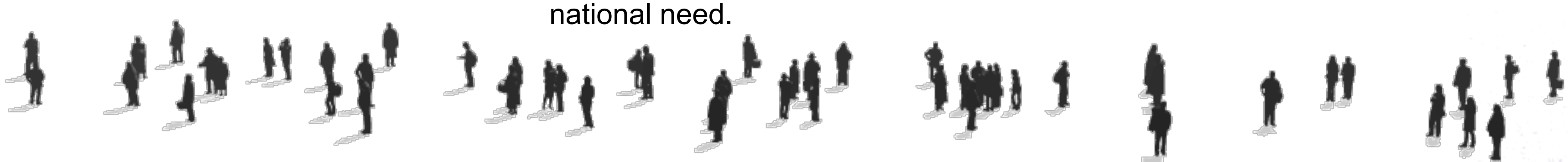
Engaging the Nation's Resources: People, Ideas and Infrastructure



Creative ideas regarding future NASA systems or solutions to national needs.

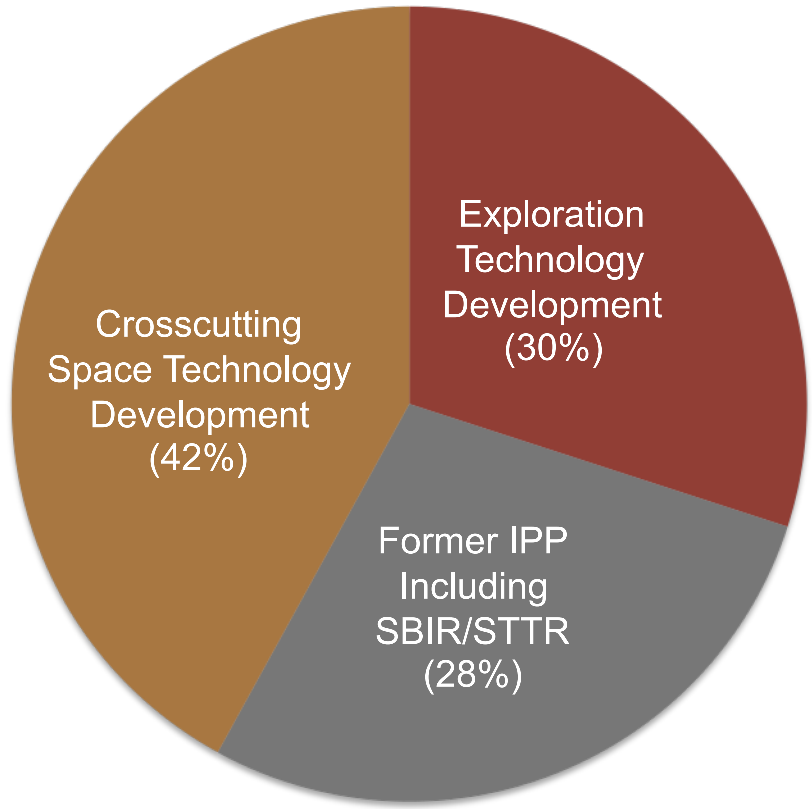
Prove feasibility of novel, early-stage ideas with potential to revolutionize a future NASA mission and/or fulfill national need.

Mature crosscutting capabilities that advance multiple future space missions to flight readiness status



Proposed FY 2012 Space Technology Budget

- In FY 2012, Space Technology is proposed at **approx. 5%** of the President's **$18.7B request for NASA**.
- The **$1024M** for Space Technology in FY 2012 includes:
  - The **SBIR/STTR** program and related technology transfer and commercialization activities (**$284M**) funded in FY 2010 through NASA's Innovative Partnership Program
  - Movement of a majority of the **Exploration Technology Development and Demonstration** activities (**$310M**) from the Exploration Systems Mission Directorate
  - The **Crosscutting technology development** activities (**$430M**) proposed as part of the President's FY 2011 request.
- All of the Space Technology programs have been **carefully formulated** over the past year, and have deep roots in technology development approaches NASA has pursued in previous years.
- The **FY 2012 request for Space Technology provides a modest increase** above the level projected in the NASA Authorization Act of 2010, consistent with the Administration's priority on federal investments in research, technology and innovation across the Nation.
  - The FY2012 request for Space Technology compares with approximately $800 million projected for these same activities in 2012 in the NASA Authorization Act of 2010



NASA FY2012 Proposed Space Technology Budget ($1024M)

NASA Technology Integration Governance

NASA Technology Executive Council

- The NASA Technology Executive Council (NTEC) is organized and chaired by the NASA Office of the Chief Technologist.
- Council membership includes the Mission Directorate AAs (or their designees), and the NASA Chief Engineer (or designee).
- The function of NTEC is to perform Agency-level technology integration, coordination and strategic planning
- 6 Meetings completed

Center Technology Council

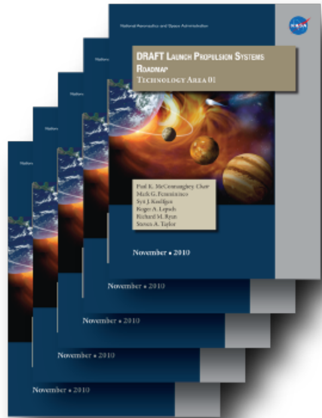
- The Center Technology Council (CTC) is organized and chaired by the NASA Office of the Chief Technologist.
- Council membership includes the Center Chief Technologist (CCT) from each NASA Center, and a representative from OCE.
- The CTC will focus upon institutionally funded activities and development of OCT programs.
- 9 Meetings completed
- Center CTs:
  - **John Hines (ARC)**
  - **David Voracek (DFRC)**
  - **Howard Ross (GRC)**
  - **Peter Hughes (GSFC)**
  - **Jonas Zmuidzinas (JPL)**
  - **John Saiz (JSC)**
  - **Karen Thompson (KSC)**
  - **Rich Antcliff (LaRC)**
  - **Andrew Keys (MSFC)**
  - **Ramona Travis (SSC)**

Governance model approved in May 2010

Space Technology Drivers

Strategic Guidance:

Strategic Plan



Technology Roadmaps

Grand Challenges

SPACE TECHNOLOGY

US Space Policy

National Needs

Space Technology Grand Challenges

A set of important space-related problems that must be solved to efficiently and economically achieve our missions.

The Grand Challenges and ST Roadmaps will be used to prioritize the technology portfolio with an eye towards NASA's future

Expand Human Presence in Space

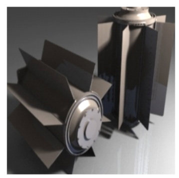
Economical Space Access

Space Health and Medicine

Telepresence in Space

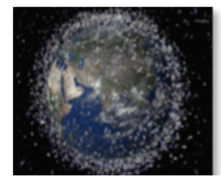
Space Colonization

Manage In-Space Resources

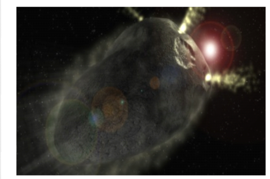


Affordable Abundant Power

Space Way Station



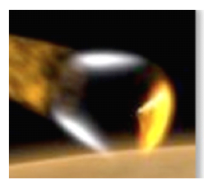
Space Debris Hazard Mitigation



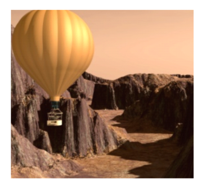
Near-Earth Object Detection and Mitigation

Enable Transformational Space Exploration and Scientific Discovery

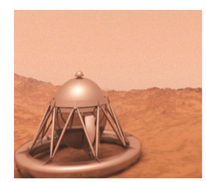
Efficient In-Space Transportation



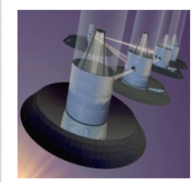
High-Mass Planetary Surface Access



All Access Mobility



Surviving Extreme Space Environments



New Tools of Discovery

http://www.nasa.gov/offices/oct/strategic_integration/grand_challenges_detail.html

NASA Space Technology Roadmap Motivation

- **Historically NASA contributed significantly to the advancement of technologies to meet both NASA missions and fuel the Nation's high tech economy**

- **More recently, funding and strategic guidance for NASA technology programs over the past two decades have endured repeated change cycles**

- **In Order for NASA to more effectively and efficiently develop space technologies moving forward, it is necessary to establish a sustained set of clearly identified and prioritized technology development goals**

- **The NASA Space Technology Roadmap, drafted by NASA, and reviewed and vetted for technology investment identification and prioritization by the NRC, will serve NASA as a decadal-like survey, to provide sustained technology investment goals.**

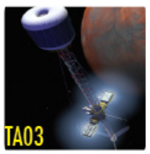
Space Technology Roadmaps
Technology Area Breakdown Structure

TA01


- LAUNCH PROPULSION SYSTEMS

TA02


- IN-SPACE PROPULSION TECHNOLOGIES

TA03


- SPACE POWER & ENERGY STORAGE

TA04


- ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

TA05


- COMMUNICATION & NAVIGATION

TA06


- HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

TA07


- HUMAN EXPLORATION DESTINA-TION SYSTEMS

TA08


- SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

TA09


- ENTRY, DESCENT & LANDING SYSTEMS

TA10


- NANOTECHNOLOGY

TA11


- MODELING, SIMULATION, INFORMA-TION TECHNOLOGY & PROCESSING

TA12


- MATERIALS, STRUCTURES, MECHAN-ICAL SYSTEMS & MANUFACTURING

TA13


- GROUND & LAUNCH SYSTEMS PROCESSING

TA14


- THERMAL MANAGEMENT SYSTEMS

http://www.nasa.gov/offices/oct/home/roadmaps/index.html

Space Technology Roadmap Process

NASA Process

8: DRAFT NASA STRs
OCT released draft Space Technology Roadmaps to the NRC & to the Public

7: Internal Reviews
Each TA Roadmap reviewed by OCT & extended teams of subject experts

6: Roadmapping Process
Preliminary roadmaps for TA areas

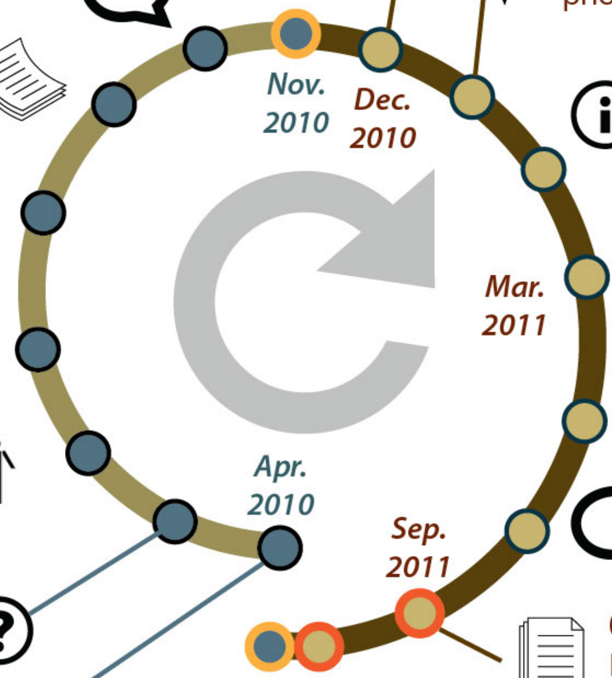
5: Form Starting Point for TA Roadmaps
Assessed past roadmaps; MD & Center inputs

4: Common Approach for TA Teams
Guidelines, assumptions, deliverables

3: Establish TA Teams
OCT established NASA internal 6-member subject expert teams for each TA, with one or two chairs

2: Identify Technology Areas
Identified Technology Areas (TAs)

1: START & Input from MDs & Center
Identified MD Goals, Missions, Architectures & Timelines; MD Technology Roadmaps & Prioritizations; Center Technology Focus Areas



9: FINAL NASA STR REPORT
NASA to release Roadmap Report

NRC Process

A: Establish NRC Teams
NRC to appoint steering committee and 6 panels

B: Identify Common Assessment Approach
NRC to establish a set of criteria to enable prioritization within and among all TAs

C: Initial Community Feedback
NRC to solicit external input from industry & academia

D: Additional Community Feedback
NRC to conduct public workshops

E: Deliberations by NRC Panels
NRC panels meet individually to prioritize technologies and suggest improvements to roadmaps

F: Documentation by NRC Panels
NRC Panels to provide written summary to Steering Committee

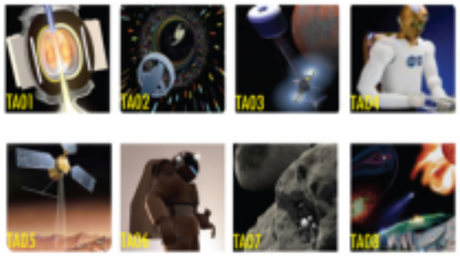
G: NRC Interim Findings
NRC to release a brief interim report that addresses high-level issues associated with the roadmaps, such as the advisability of modifying the number or technical focus of the draft NASA roadmaps

H: FINAL NRC REPORT
With decisional information, including: summary of findings and recommendations for each of the roadmaps; integrated outputs from the workshops and panels ; identify key common threads and issues; priorities, by group (e.g., high, medium, low), of the highest priority technologies from the TAs

NASA Space Technology Roadmaps Process

Technology Area Breakdown Structure

National Aeronautics and Space Administration



TA01 • LAUNCH PROPULSION SYSTEMS

Solid Rocket Propulsion Systems
- Propellants
- Case Materials
- Nozzle Systems
- Hybrid Rocket Propulsion Systems
- Fundamental Solid Propulsion Technologies

Liquid Rocket Propulsion Systems
- LH/LOX Based
- RP/LOX Based
- CH/LOX Based
- Detonation Wave Engines (Closed Cycle)
- Propellants
- Fundamental Liquid Propulsion Technologies

Air Breathing Propulsion Systems
- TBCC
- RBCC
- Detonation Wave Engines (Open Cycle)
- Turbine Based Jet Engines (Flyback Boosters)
- Ramjet/Scramjet Engines (Accelerators)
- Deeply-cooled Air Cycles
- Air Collection & Enrichment System
- Fundamental Air Breathing Propulsion Technologies

Ancillary Propulsion Systems
- Auxiliary Control Systems
- Main Propulsion Systems (Excluding Engines)
- Launch Abort Systems
- Thrust Vector Control Systems
- Health Management & Sensors
- Pyro & Separation Systems
- Fundamental Ancillary Propulsion Technologies

Unconventional / Other Propulsion Systems
- Ground Launch Assist
- Air Launch / Drop Systems
- Space Tether Assist
- Beamed Energy / Energy Addition
- Nuclear
- High Energy Density Materials/Propellants

TA02 • IN-SPACE PROPULSION TECHNOLOGIES

Chemical Propulsion
- Liquid Storable
- Liquid Cryogenic
- Gels
- Solid
- Hybrid
- Cold Gas/Warm Gas
- Micro-propulsion

Non-Chemical Propulsion
- Electric Propulsion
- Solar Sail Propulsion
- Thermal Propulsion
- Tether Propulsion

Advanced (TRL <3) Propulsion Technologies
- Beamed Energy Propulsion
- Electric Sail Propulsion
- Fusion Propulsion
- High Energy Density Materials
- Antimatter Propulsion
- Advanced Fission
- Breakthrough Propulsion

Supporting Technologies
- Engine Health Monitoring & Safety
- Propellant Storage & Transfer
- Materials & Manufacturing Technologies
- Heat Rejection
- Power

TA03 • SPACE POWER & ENERGY STORAGE

Power Generation
- Energy Harvesting
- Chemical (Fuel Cells, Heat Engines)
- Solar (Photo-Voltaic & Thermal)
- Radioisotope
- Fission
- Fusion

Energy Storage
- Batteries
- Flywheels
- Regenerative Fuel Cells

Power Management & Distribution
- FDIR
- Management & Control
- Distribution & Transmission
- Wireless Power Transmission
- Conversion & Regulation

Cross Cutting Technology
- Analytical Tools
- Green Energy Impact
- Multi-functional Structures
- Alternative Fuels

TA04 • ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

Sensing & Perception
- Stereo Vision
- LIDAR
- Proximity Sensing
- Sensing Non-Geometric Terrain Properties
- Estimating Terrain Mechanical Properties
- Tactile Sensing Arrays
- Gravity Sensors & Celestial Nav.
- Terrain Relative Navigation
- Real-time Self-calibrating of Hand-eye Systems

Mobility
- Simultaneous Localiz. & Mapping
- Hazard Detection Algorithms
- Active Illumination
- 3-D Path Planning w/ Uncertainty
- Long-life Extr. Enviro. Mechanisms
- Robotic Jet Backpacks
- Smart Tethers
- Robot Swarms
- Walking in Micro-g

Manipulation
- Motion Planning Alg., High DOF
- Sensing & Control
- Robot Arms (light, high strength)
- Dexterous Manipul., Robot Hands
- Sensor Fusion for Grasping
- Grasp Planning Algorithms
- Robotic Drilling Mechanisms
- Multi-arm / Finger Manipulation
- Planning with Uncertainty

Human-Systems Integration
- Crew Decision Support Systems
- Immersive Visualization
- Distributed Collaboration
- Multi Agent Coordination
- Haptic Displays
- Displaying Range Data to Humans

Autonomy
- Spacecraft Control Systems
- Vehicle Health, Prog/Diag Systems
- Human Life Support Systems
- Planning/Scheduling Resources
- Operations
- Integrated Systems Health Management
- FDIR & Diagnosis
- System Monitoring & Prognosis
- V&V of Complex Adaptive Sys's
- Automated Software Generation
- Software Reliability
- Semi Automatic Systems

Auton. Rendezvous & Docking
- Rendezvous and Capture
- Low impact & Androgenous Docking Systems & Interfaces
- Relative Navigation Sensors
- Robust AR&D GN&C Algorithms & FSW
- Onboard Mission Manager
- AR&D Integration & Standardiz.n

RTA Systems Engineering
- Human safety
- Refueling Interfaces & Assoc. Tools
- Modular / Serviceable Interfaces
- High Perf., Low Power Onboard Computers
- Environment Tolerance
- Thermal Control
- Robot-to-Suit Interfaces
- Common Human-Robot Interfaces
- Crew Self Sufficiency

TA05 • COMMUNICATION & NAVIGATION

Optical Comm. & Navigation
- Detector Development
- Large Apertures
- Lasers
- Acquisition & Tracking
- Atmospheric Mitigation

Radio Frequency Communications
- Spectrum Efficient Technologies
- Power Efficient Technologies
- Propagation
- Flight & Ground Systems
- Earth Launch & Reentry Comm.
- Antennas

Internetworking
- Disruptive Tolerant Networking
- Adaptive Network Topology
- Information Assurance
- Integrated Network Management

Position, Navigation, and Timing
- Timekeeping
- Time Distribution
- Onboard Auto Navigation & Maneuver
- Sensors & Vision Processing Systems
- Relative & Proximity Navigation
- Auto Precision Formation Flying
- Auto Approach & Landing

Integrated Technologies
- Radio Systems
- Ultra Wideband
- Cognitive Networks
- Science from the Comm. System
- Hybrid Optical Comm. & Nav. Sensors
- RF/Optical Hybrid Technology

Revolutionary Concepts
- X-Ray Navigation
- X-Ray Communications
- Neutrino-Based Navigation & Tracking
- Quantum Key Distribution
- Quantum Communications
- SQIF Microwave Amplifier
- Reconfigurable Large Apertures

TA06 • HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

Environmental Control & Life Support Systems & Habitation Sys.
- Air Revitalization
- Water Recovery & Management
- Waste Management
- Habitation

Extravehicular Activity Systems
- Pressure Garment
- Portable Life Support System
- Power, Avionics and Software

Human Health & Performance
- Medical Diagnosis / Prognosis
- Long-Duration Health
- Behavioral Health & Performance
- Human Factors & Performance

Environmental Monitoring, Safety & Emergency Response
- Sensors: Air, Water, Microbial, etc.
- Fire: Detection, Suppression
- Protective Clothing / Breathing
- Remediation

Radiation
- Risk Assessment Modeling
- Radiation Mitigation
- Protection Systems
- Space Weather Prediction
- Monitoring Technology

TA07 • HUMAN EXPLORATION DESTINATION SYSTEMS

In-Situ Resource Utilization
- Destination Reconnaissance, Prospecting, & Mapping
- Resource Acquisition
- Consumables Production
- Manufacturing & Infrastructure Emplacement

Sustainability & Supportability
- Logistics Systems
- Maintenance Systems
- Repair Systems

"Advanced" Human Mobility Systems
- EVA Mobility
- Surface Mobility
- Off-Surface Mobility

"Advanced" Habitat Systems
- Integrated Habitat Systems
- Habitat Evolution

Mission Operations & Safety
- Crew Training
- Environmental Protection
- Remote Mission Operations
- Planetary Safety

Cross-Cutting Systems
- Modeling, Simulations & Destination Characterization
- Construction & Assembly
- Dust Prevention & Mitigation

TA08 • SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

Remote Sensing Instruments / Sensors
- Detectors & Focal Planes
- Electronics
- Optical Components
- Microwave / Radio
- Lasers
- Cryogenic / Thermal

Observatories
- Mirror Systems
- Structures & Antennas
- Distributed Aperture

In-Situ Instruments / Sensor
- Particles: Charged & Neutral
- Fields & Waves
- In-Situ

TA09 • ENTRY, DESCENT & LANDING SYSTEMS

Aeroassist & Atmospheric Entry
- Rigid Thermal Protection Systems
- Flexible Thermal Protection Systems
- Rigid Hypersonic Decelerators
- Deployable Hypersonic Decelerators
- Instrumentation & Health Monitoring
- Entry Modeling & Simulation

Descent
- Attached Deployable Decelerators
- Trailing Deployable Decelerators
- Supersonic Retropropulsion
- GN&C Sensors
- Descent Modeling & Simulation

Landing
- Touchdown Systems
- Egress & Deployment Systems
- Propulsion Systems
- Large Body GN&C
- Small Body Systems
- Landing Modeling & Simulation

Vehicle Systems Technology
- Architecture Analyses
- Separation Systems
- System Integration & Analyses
- Atmosphere & Surface Characterization

TA10 • NANOTECHNOLOGY

Engineered Materials & Structures
- Lightweight Structures
- Damage Tolerant Systems
- Coatings
- Adhesives
- Thermal Protection & Control

Energy Generation & Storage
- Energy Storage
- Energy Generation

Propulsion
- Propellants
- Propulsion Components
- In-Space Propulsion

Sensors, Electronics & Devices
- Sensors & Actuators
- Nanoelectronics
- Miniature Instruments

TA11 • MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING

Computing
- Flight Computing
- Ground Computing

Modeling
- Software Modeling & Model-Checking
- Integrated Hardware & Software Modeling
- Human-System Performance Modeling
- Science & Engineering Modeling
- Frameworks, Languages, Tools & Standards

Simulation
- Distributed Simulation
- Integrated System Lifecycle Simulation
- Simulation-Based Systems Engineering
- Simulation-Based Training & Decision Support Systems

Information Processing
- Science, Engineering & Mission Data Lifecycle
- Intelligent Data Understanding
- Semantic Technologies
- Collaborative Science & Engineering
- Advanced Mission Systems

TA12 • MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

Materials
- Lightweight Structure
- Computational Design
- Flexible Material Systems
- Environment
- Special Materials

Structures
- Lightweight Concepts
- Design & Certification Methods
- Reliability & Sustainment
- Test Tools & Methods
- Innovative, Multifunctional Concepts

Mechanical Systems
- Deployables, Docking and Interfaces
- Mechanism Life Extension Systems
- Electro-mechanical, Mechanical & Micromechanisms
- Design & Analysis Tools and Methods
- Reliability / Life Assessment / Health Monitoring
- Certification Methods

Manufacturing
- Manufacturing Processes
- Intelligent Integrated Manufacturing and Cyber Physical Systems
- Electronics & Optics Manufacturing Process
- Sustainable Manufacturing

Cross-Cutting
- Nondestructive Evaluation & Sensors
- Model-Based Certification & Sustainment Methods
- Loads and Environments

TA13 • GROUND & LAUNCH SYSTEMS PROCESSING

Technologies to Optimize the Operational Life-Cycle
- Storage, Distribution & Conservation of Fluids
- Automated Alignment, Coupling, & Assembly Systems
- Autonomous Command & Control for Ground and Integrated Vehicle/Ground Systems

Environmental and Green Technologies
- Corrosion Prevention, Detection, & Mitigation
- Environmental Remediation & Site Restoration
- Preservation of Natural Ecosystems
- Alternate Energy Prototypes

Technologies to Increase Reliability and Mission Availability
- Advanced Launch Technologies
- Environment-Hardened Materials and Structures
- Inspection, Anomaly Detection & Identification
- Fault Isolation and Diagnostics
- Prognostics Technologies
- Repair, Mitigation, and Recovery Technologies
- Communications, Networking, Timing & Telemetry

Technologies to Improve Mission Safety/Mission Risk
- Range Tracking, Surveillance & Flight Safety Technologies
- Landing & Recovery Systems & Components
- Weather Prediction and Mitigation
- Robotics / Telerobotics
- Safety Systems

TA14 • THERMAL MANAGEMENT SYSTEMS

Cryogenic Systems
- Passive Thermal Control
- Active Thermal Control
- Integration & Modeling

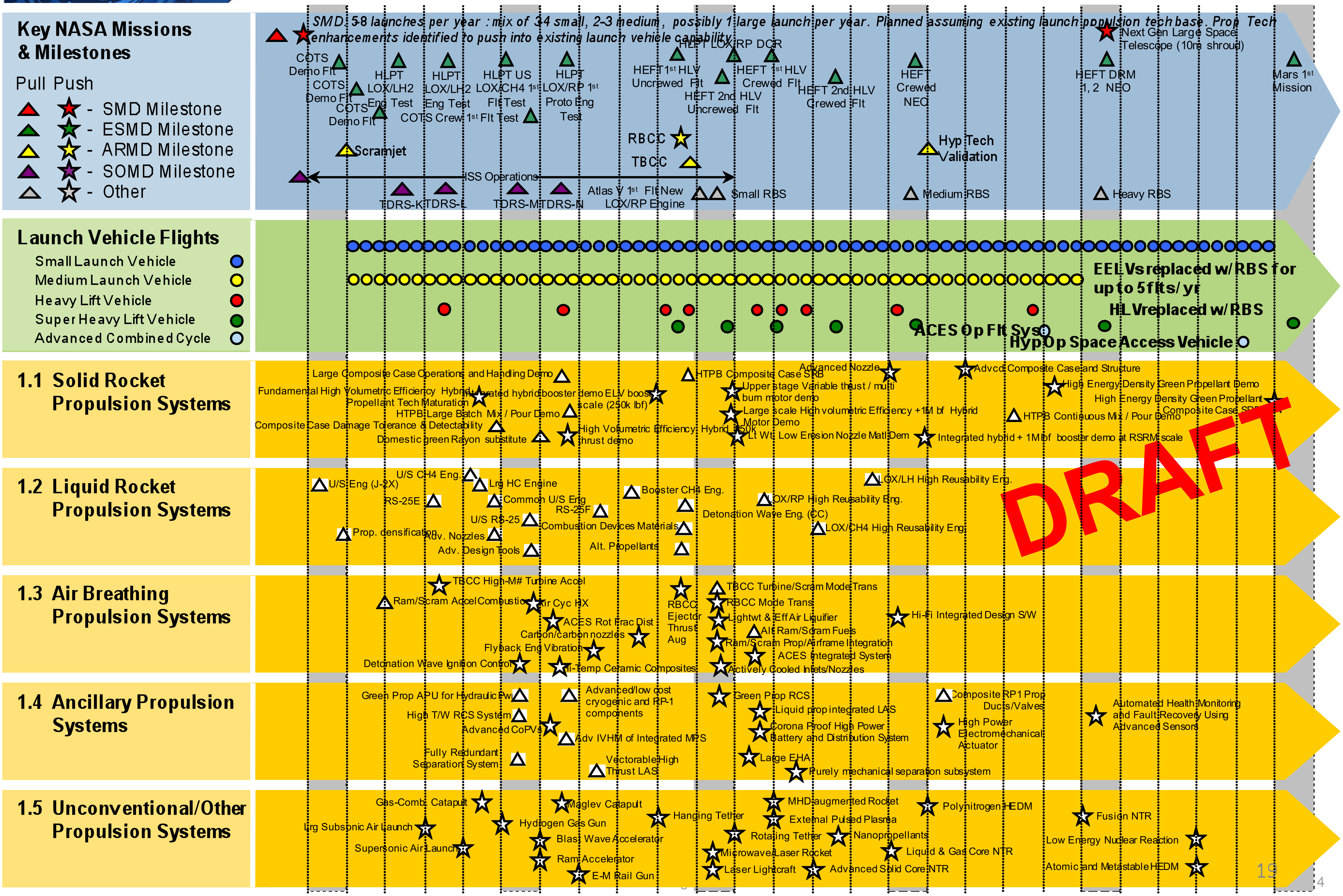
Thermal Control Systems
- Heat Acquisition
- Heat Transfer
- Heat Rejection & Energy Storage

Thermal Protection Systems
- Entry / Ascent TPS
- Plume Shielding (Convective & Radiative)
- Sensor Systems & Measurement Technologies

Space Technology Roadmaps **STR • TABS**

TECHNOLOGY AREA BREAKDOWN STRUCTURE

EXAMPLE - TA01: Launch Propulsion Systems Technology Roadmap



EXAMPLE - TA03: Power and Energy Storage Roadmap

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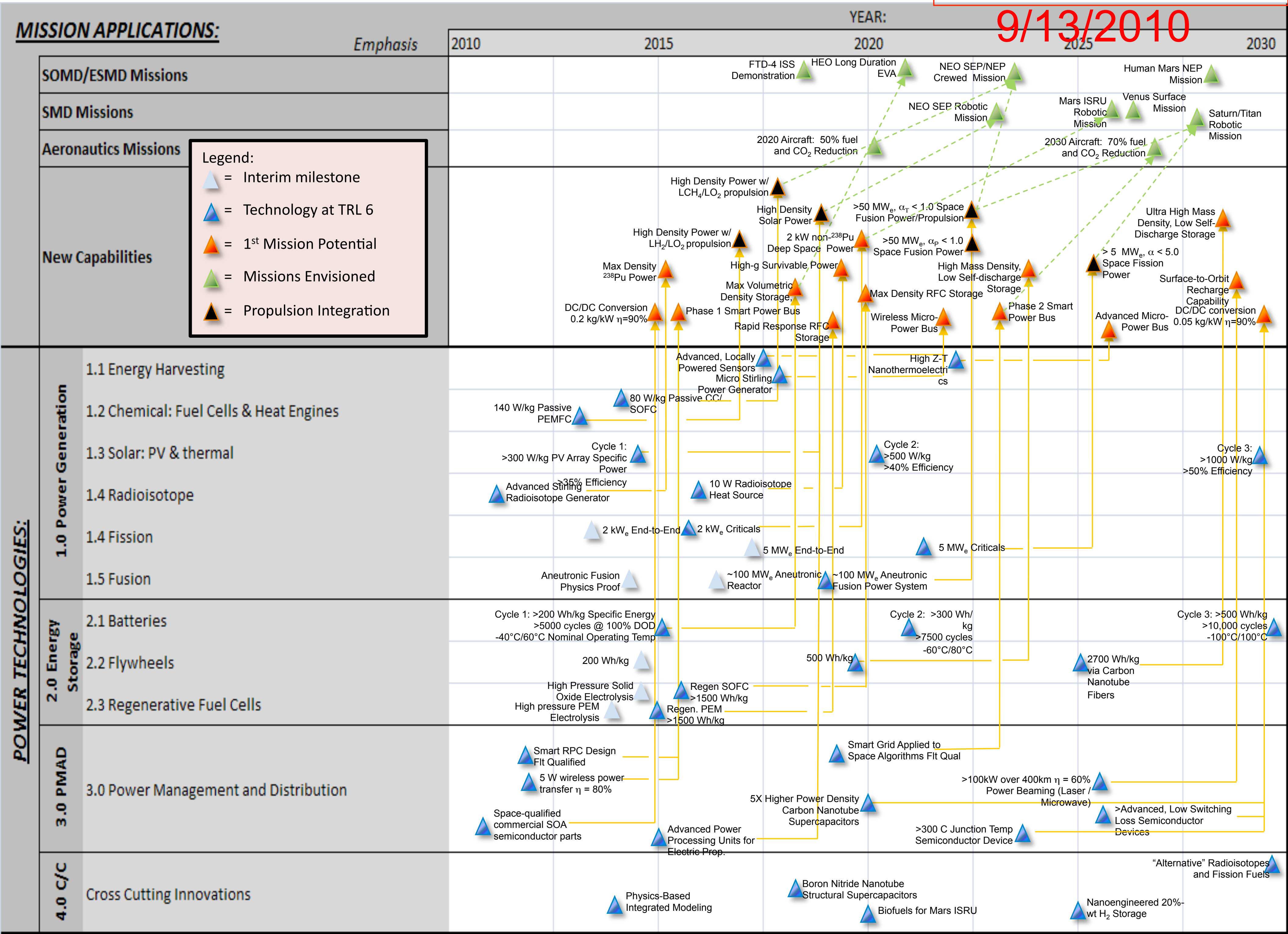
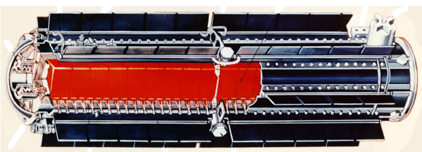
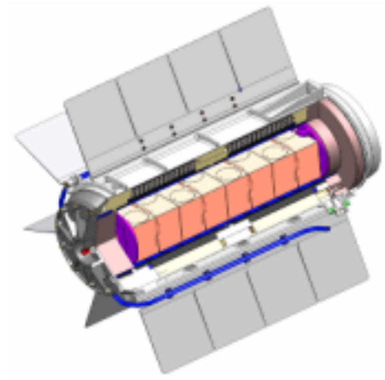


EXAMPLE - TA03: Power Generation: Radioisotope Power Systems





State-of-Practice Systems

- SOP Systems: GPHS RTG, MMRTG
- Performance Capabilities:
  - 6-8% efficiency,
  - Specific Power 3-5 W/kg,
  - Life: > 15 years
- Applications:
  - Outer Planet spacecraft, Mars Rovers
- Limitations: Low efficiency and heavy

ASRG
8 W/kg, 30%

ARTG
8 W/kg, 10-15%

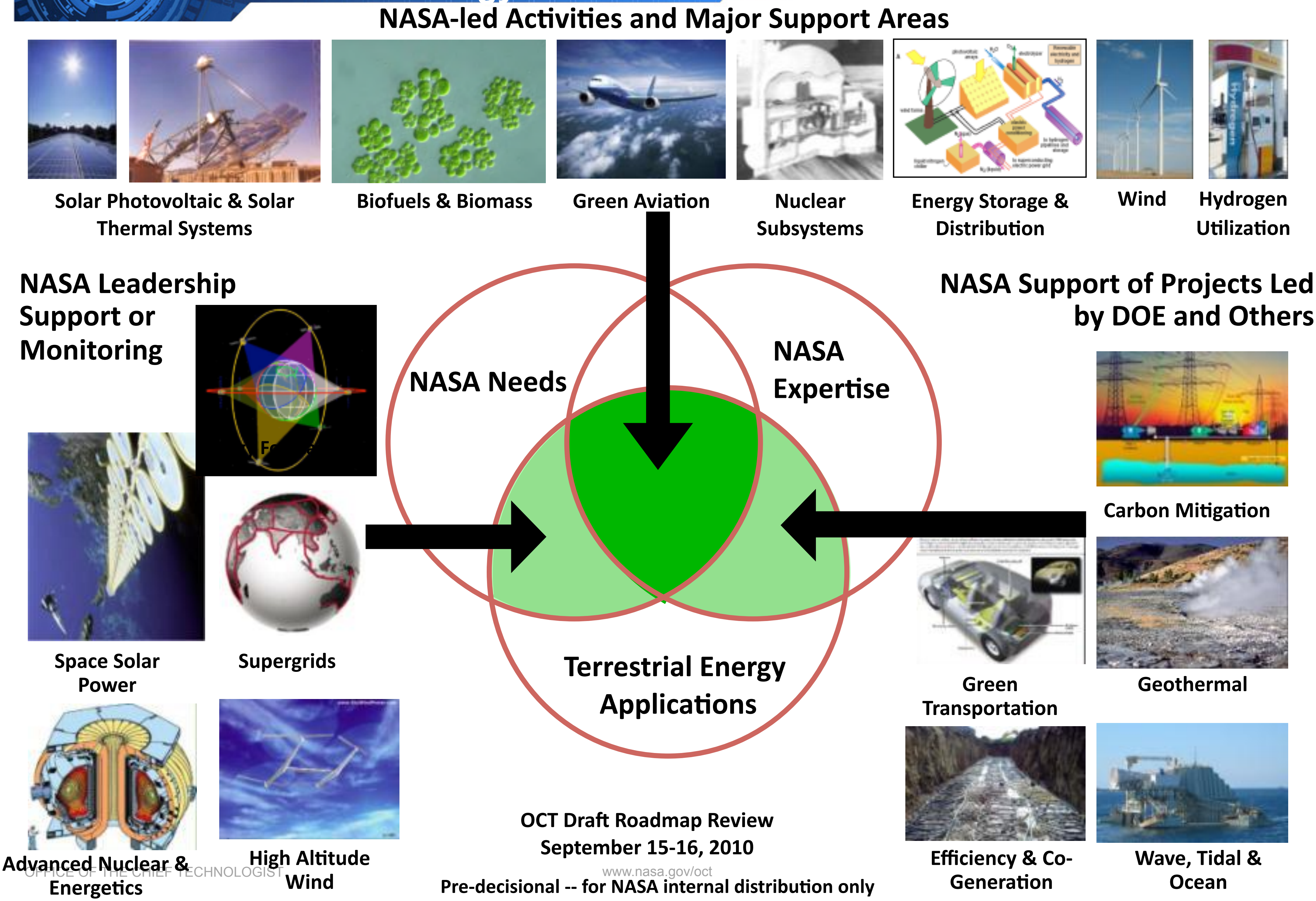
TPV 8 W/kg, 15%

Advanced Radioisotope Power Systems

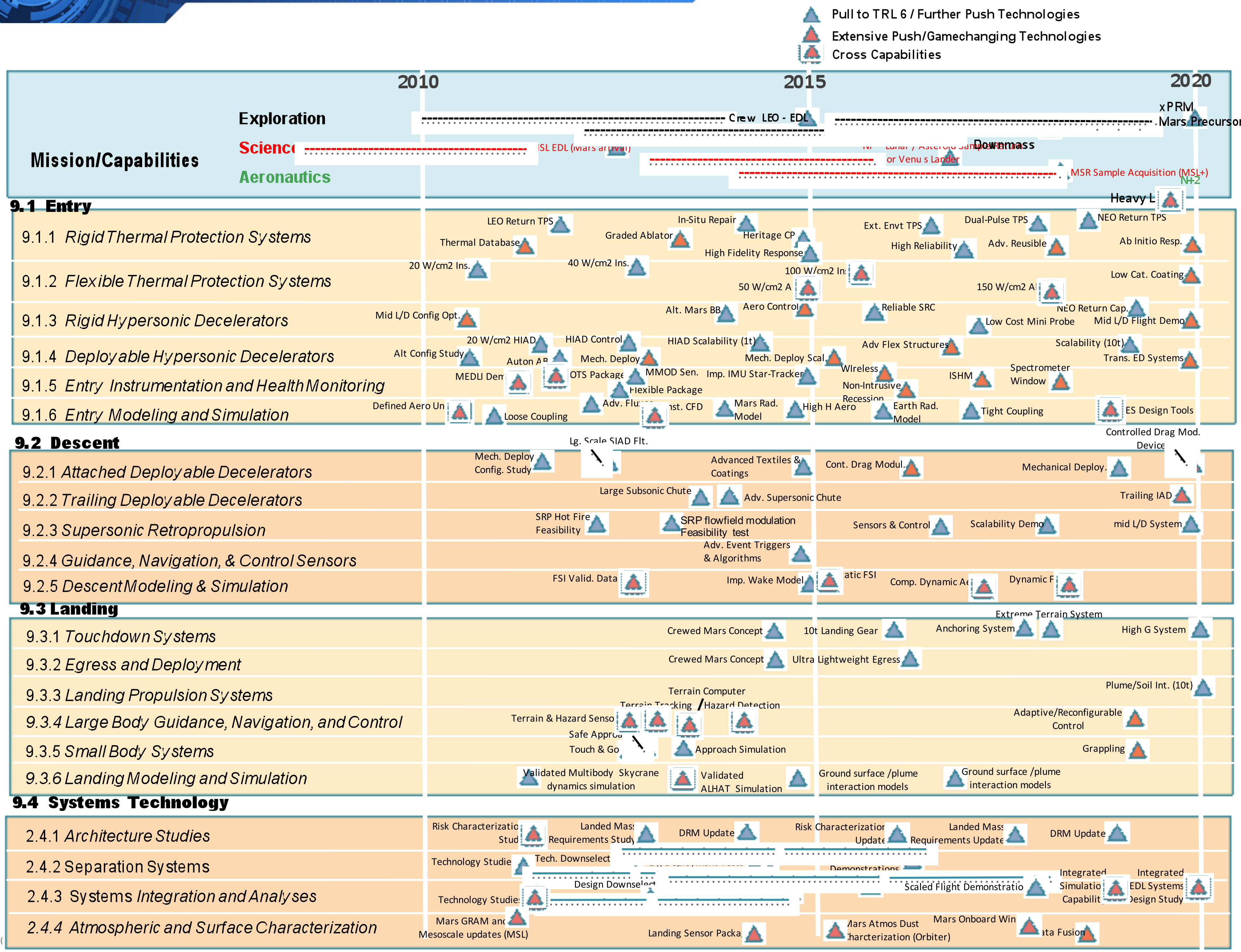
- Capabilities: High Efficiency: > 28% Specific Power: > 8 We/Kg; Life > 14 years
- Challenges: High efficiency power conversion systems with very long life capability.
- Status: SMD is developing advanced RPSs for future space science missions.
- Potential Space Applications: Outer Planet Flagship missions (Up to 1 kWe) & Rovers, (1 - 2 kWe)

Enables nuclear powered outer planetary science and Mars rover

EXAMPLE - TA03: Where NASA Can Make a Difference In Green Energy

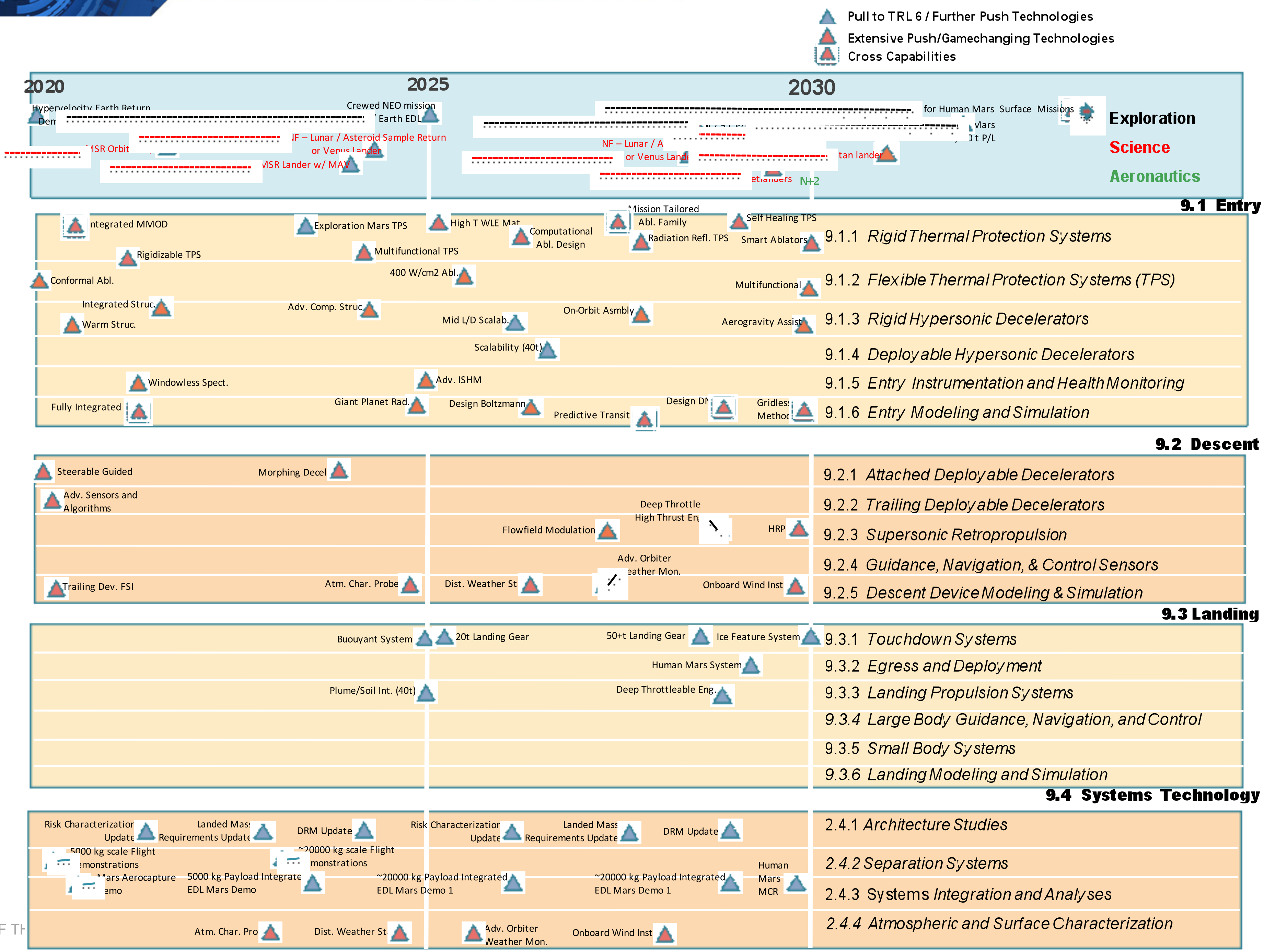


EDL Roadmap



Pull to TRL 6 / Further Push Technologies
Extensive Push/Gamechanging Technologies
Cross Capabilities
2010
2015
2020
Mission/Capabilities
Exploration
Science
Aeronautics
Crew LEO - EDL
xPRM
Mars Precursor
Downmass
or Venus Lander
MSR Sample Acquisition (MSL+)
N+2
Heavy L
9.1 Entry
9.1.1 Rigid Thermal Protection Systems
9.1.2 Flexible Thermal Protection Systems
9.1.3 Rigid Hypersonic Decelerators
9.1.4 Deployable Hypersonic Decelerators
9.1.5 Entry Instrumentation and Health Monitoring
9.1.6 Entry Modeling and Simulation
LEO Return TPS
Thermal Database
In-Situ Repair
Graded Ablator
Heritage CP
High Fidelity Response
Ext. Envt TPS
High Reliability
Dual-Pulse TPS
Adv. Reusible
NEO Return TPS
Ab Initio Resp.
20 W/cm2 Ins.
40 W/cm2 Ins.
100 W/cm2 In
50 W/cm2 A
150 W/cm2 A
Low Cat. Coating
Mid L/D Config Opt.
Alt. Mars BB
Aero Control
Reliable SRC
Low Cost Mini Probe
NEO Return Cap.
Mid L/D Flight Demo
Alt Config Study
20 W/cm2 HIAD
HIAD Control
HIAD Scalability (1t)
Mech. Deploy
Mech. Deploy Scal.
Adv Flex Structures
Scalability (10t)
Trans. ED Systems
MEDLI Dem
OTS Package
MMOD Sen.
Imp. IMU Star-Tracker
Flexible Package
Wireless
Non-Intrusive Recession
ISHM
Spectrometer Window
Defined Aero Un
Loose Coupling
Adv. Flu
nst. CFD
Mars Rad. Model
High H Aero
Earth Rad. Model
Tight Coupling
ES Design Tools
9.2 Descent
9.2.1 Attached Deployable Decelerators
9.2.2 Trailing Deployable Decelerators
9.2.3 Supersonic Retropropulsion
9.2.4 Guidance, Navigation, & Control Sensors
9.2.5 Descent Modeling & Simulation
Lg. Scale SIAD Flt.
Controlled Drag Mod. Device
Mech. Deploy Config. Study
Advanced Textiles & Coatings
Cont. Drag Modul.
Mechanical Deploy.
Large Subsonic Chute
Adv. Supersonic Chute
Trailing IAD
SRP Hot Fire Feasibility
SRP flowfield modulation Feasibility test
Sensors & Control
Scalability Demo
mid L/D System
Adv. Event Triggers & Algorithms
FSI Valid. Data
Imp. Wake Model
atic FSI
Comp. Dynamic A
Dynamic F
9.3 Landing
9.3.1 Touchdown Systems
9.3.2 Egress and Deployment
9.3.3 Landing Propulsion Systems
9.3.4 Large Body Guidance, Navigation, and Control
9.3.5 Small Body Systems
9.3.6 Landing Modeling and Simulation
Crewed Mars Concept
10t Landing Gear
Anchoring System
Extreme Terrain System
High G System
Ultra Lightweight Egress
Plume/Soil Int. (10t)
Terrain Computer
Terrain Tracking / Hazard Detection
Terrain & Hazard Senso
Safe Appro
Adaptive/Reconfigurable Control
Touch & Go
Approach Simulation
Grappling
Validated Multibody Skycrane dynamics simulation
Validated ALHAT Simulation
Ground surface /plume interaction models
9.4 Systems Technology
2.4.1 Architecture Studies
2.4.2 Separation Systems
2.4.3 Systems Integration and Analyses
2.4.4 Atmospheric and Surface Characterization
Risk Characterizatio Stud
Landed Mass Requirements Study
DRM Update
Risk Characterization Update
Landed Mass Requirements Update
Technology Studie
Tech. Downselect
Demonstrations
Design Downselect
Scaled Flight Demonstratio
Integrated Simulatio Capabilit
Integrated EDL Systems Design Study
Mars GRAM and Mesoscale updates (MSL)
Landing Sensor Packa
Mars Atmos Dust Charcterization (Orbiter)
Mars Onboard Win
ata Fusion

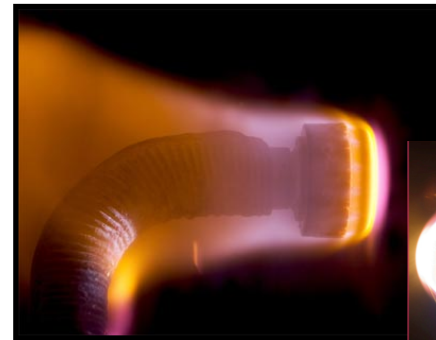
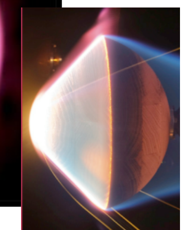
EDL Roadmap

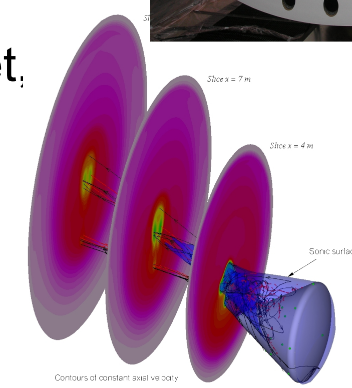


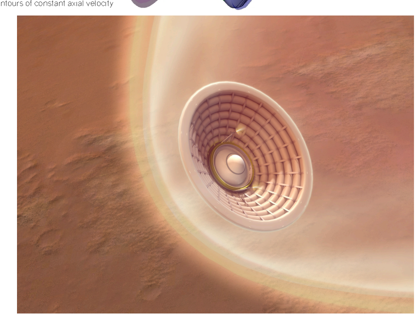
Pull to TRL 6 / Further Push Technologies
Extensive Push/Gamechanging Technologies
Cross Capabilities
2020
2025
2030
Hypervelocity Earth Return
Crewed NEO mission
Earth EDL
MSR Orbit
NF – Lunar / Asteroid Sample Return
or Venus lander
MSR Lander w/ MAV
NF – Lunar / A
or Venus Land
for Human Mars Surface Missions
Mars
tan lander
N+2
Exploration
Science
Aeronautics
9.1 Entry
Integrated MMOD
Exploration Mars TPS
High T WLE Mat
Computational
Abl. Design
Mission Tailored
Abl. Family
Self Healing TPS
Radiation Refl. TPS
Smart Ablators
Rigidizable TPS
Multifunctional TPS
9.1.1 Rigid Thermal Protection Systems
Conformal Abl.
400 W/cm2 Abl.
Multifunctional
9.1.2 Flexible Thermal Protection Systems (TPS)
Integrated Struc.
Warm Struc.
Adv. Comp. Struc.
Mid L/D Scalab.
On-Orbit Asmbly
Aerogravity Assist
9.1.3 Rigid Hypersonic Decelerators
Scalability (40t)
9.1.4 Deployable Hypersonic Decelerators
Windowless Spect.
Adv. ISHM
9.1.5 Entry Instrumentation and Health Monitoring
Fully Integrated
Giant Planet Rad.
Design Boltzmann
Predictive Transit
Design DN
Gridless Method
9.1.6 Entry Modeling and Simulation
9.2 Descent
Steerable Guided
Morphing Decel
9.2.1 Attached Deployable Decelerators
Adv. Sensors and Algorithms
Deep Throttle
High Thrust Eng
9.2.2 Trailing Deployable Decelerators
Flowfield Modulation
HRP
9.2.3 Supersonic Retropropulsion
Adv. Orbiter
Weather Mon.
9.2.4 Guidance, Navigation, & Control Sensors
Trailing Dev. FSI
Atm. Char. Probe
Dist. Weather St.
Onboard Wind Inst
9.2.5 Descent Device Modeling & Simulation
9.3 Landing
Buouyant System
20t Landing Gear
50+t Landing Gear
Ice Feature System
9.3.1 Touchdown Systems
Human Mars System
9.3.2 Egress and Deployment
Plume/Soil Int. (40t)
Deep Throttleable Eng.
9.3.3 Landing Propulsion Systems
9.3.4 Large Body Guidance, Navigation, and Control
9.3.5 Small Body Systems
9.3.6 Landing Modeling and Simulation
9.4 Systems Technology
Risk Characterization Update
Landed Mass Requirements Update
DRM Update
Risk Characterization Update
Landed Mass Requirements Update
DRM Update
2.4.1 Architecture Studies
5000 kg scale Flight Demonstrations
~20000 kg scale Flight Demonstrations
2.4.2 Separation Systems
Mars Aerocapture Demo
5000 kg Payload Integrated EDL Mars Demo
~20000 kg Payload Integrated EDL Mars Demo 1
~20000 kg Payload Integrated EDL Mars Demo 1
Human Mars MCR
2.4.3 Systems Integration and Analyses
Atm. Char. Pro
Dist. Weather St
Adv. Orbiter Weather Mon.
Onboard Wind Inst
2.4.4 Atmospheric and Surface Characterization

Entry: Major Elements

- **Entry Systems**
  - Major technology advances to the current SOA required for several missions, notably high speed Earth return, human exploration of Mars, giant planet probes, and high reliability systems for human and sample return missions
  - Significant enhancement to the current SOA possible for other missions, including Mars, Venus and Titan exploration, crewed and robotic Earth entry, and low cost access to space
- **Aerocapture**
  - No major technology developments identified that preclude a flight demonstration at Earth or another planet, other than mission-specific requirements shared with Entry Systems.
- **Aerobraking**
  - Established technology at Mars and Venus. Significant advances to SOA possible by automating the process (less human in the loop), and by development of high-temperature solar panels.

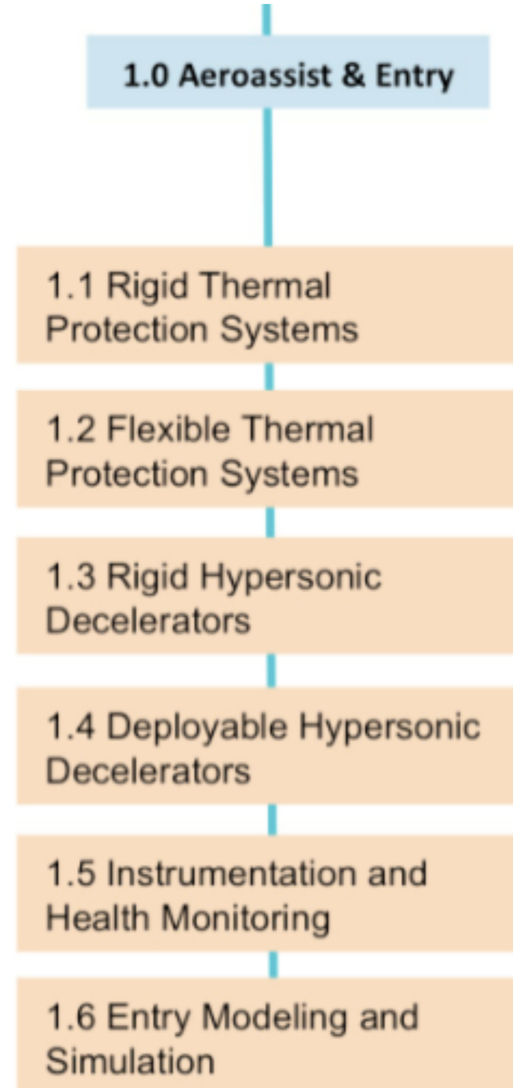







Entry: Major Technological Challenges

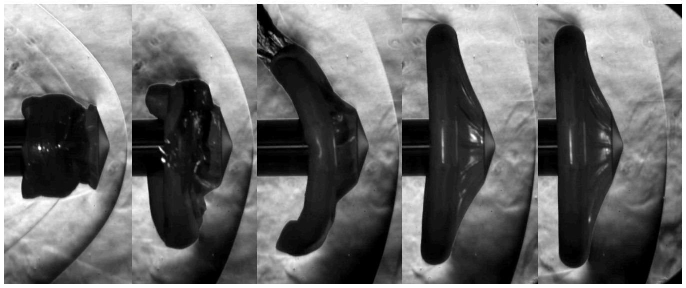
- Wide range of destination and mission specific requirements necessitate a range of parallel investments. There is no "one size fits all" solution
- Availability and suitability of ground facilities for testing and validation (to be discussed later in this briefing)
- Long term retention of critical EDL-unique skill sets (including training the next generation of EDL engineers)
- Likely requirement for system level validation via flight test of many of the considered technologies

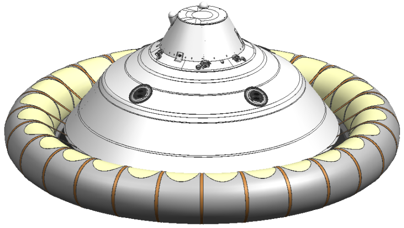


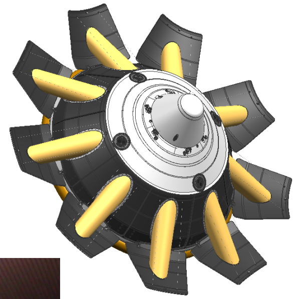
The inability to "test as you fly" in most cases puts additional pressure on high fidelity physics-based simulation capability as a critical link in ground-to-flight traceability. Robust investment in improved physics-based performance models is critical to ensuring system robustness and reliability.

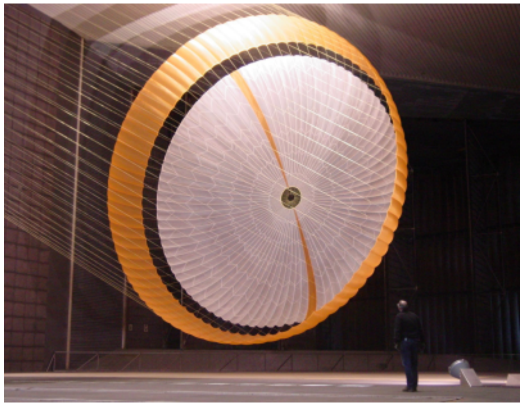
Descent: Key Technology Areas

- Attached Deployable Decelerators
  - Both inflated and mechanically deployed
  - Adv coatings and textiles
- Trailing Deployable Decelerators
  - Large subsonic parachutes (Mars application)
  - Adv supersonic parachutes
- Supersonic Retropropulsion
  - Flowfield modulation
  - Deep throttle, high-thrust propulsion
- GN&C Sensors
  - Adv triggers for staging
  - On board atmosphere/wind sensing









Landing: Key Technology Areas

- Surface sensing
  - Terrain tracking
  - Hazard location determination
- Descent propulsion
  - Deeply-throttled efficient rocket motors (TA-02)
  - Plume-surface interaction mitigation and modeling
- Touchdown systems
  - Energy absorption
  - Stability
  - High-G survivable systems
  - Egress and deployment systems
- Small body guidance

Vehicle Systems Technology

- Successful EDL capabilities require comprehensive and integrated technology solutions at the component, sub-system and system level
  - Significant technology development challenges will exist for new EDL staging/ separation systems and vehicle level integration of individual technological capabilities
  - EDL on atmospheric bodies is significantly impacted by knowledge and characterization of atmospheric profile variations and persistence
- Technology Area Separated into Three Categories
  - Separation Systems
  - Vehicle Technology
  - Atmospheric Modeling and Surface Characterization

NASA Space Technology: Part of a Broader National Strategy

- **Technological leadership is the "Space Race" of the 21st Century:** *Space Technology* is the central NASA contribution to revitalize research, technology and innovation for the Nation

- **Enabling Our Future in Space:** Invest in high payoff, disruptive technology that industry cannot tackle today, to support NASA science and exploration while providing capabilities and lowering the cost of other government agencies and commercial space activities

- **NASA at the Cutting Edge:** Pushing the boundaries of aeroscience and taking informed-risk, Space Technology keeps NASA and our Nation at the cutting-edge

- **Engage Innovators across the Nation:** Select development teams across academia, industry, and the NASA Centers based on technical merit.

- **Investments in our Future**: In FY 2012, the President's Budget Request for Space Technology is approximately 5% of the President's $18.7B request for NASA.

- **NASA makes a difference in our lives everyday**: In addition to providing a more vital and productive aerospace future, by investing in Space Technology, NASA will continue to make a difference in our lives everyday.